NOTES ON SHIP DESIGN AND RESEARCH

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This paper has been prepared as a general discussion of ship design and research and is not intended to be a technical contribution to the engineering field of naval architecture. No attempt has been made to present solutions to the many problems involved in ship design but rather to indicate where the author believes additional effort may be profitable. Some suggestions are made where improvements in ships may be sought in the light of the results of recent research. The point is made that naval architecture is still too much "art" and not enough "science".

Throughout the many hundreds of years of shipbuilding and ship operation the designer has approached each new ship design with a great deal of conservatism. A new ship has been only a small step ahead of its predecessors in a technological sense. There are of course notable examples of ships which belie this statement. The "Ark", the "Great Eastern", the "United States", and the "Nautilus" are ships which involved engineering advances. The "Great Eastern" was perhaps too far ahead of its time; it was not an economic success. Nevertheless, from a technical standpoint it was certainly a much greater step than normal and involved difficult engineering problems due to its large size.

The "United States" is a fine ship and an outstanding example of American ship design. However, the engineering "know how" had been available long before her construction and in terms of technical advancement she is not so remarkable.

(Numbers in the text refer to references)

The submarine "Nautilus" is outstanding technically and is first in the use of nuclear power for any form of transportation. In the opinion of many the development and successful operation of this ship overshadows the great scientific achievements of the earth satellites. The "Nautilus" is a prime example of what intensive research and engineering can do when made possible by the availability of almost unlimited funds, a tremendous advantage in such an enterprise.

It can be argued with considerable merit that to embark on the construction of such an expensive piece of hardware as a large ship which has designed into it quantum jumps in engineering is too great an economic risk for private industry to undertake. There are available today, however, theoretical and experimental approaches which, if applied to ship design and operation in the same way as they are being applied to design problems in other fields, will enable greater improvements to be made in ships without the necessity of the risk of actually building a prototype for trials. These approaches have not yet been fully exploited in the ship design field.

The shipbuilding industry and the ship operators are faced with serious economic problems. It cannot be said that this situation is new nor is it restricted to ships. Look at the railroads. What is happening to them can happen to shipping. The railroad as a means of transportation reached its peak during the early part of the present century. Today the railroads are in financial difficulties. Passenger traffic, except for commuter travel, has all but vanished. The private automobile and the airplane have taken most of it and are rapidly taking the rest. A recent article in a railway magazine forecast the complete disappearance of sleeping car service in the U. S. within a few years. The article also expressed pessimism as to a solution to the problem and pointed out that the only advantage which can be offered in favor of the railroads is that they remain the safest form of land transportation. It has been reported (1) that the railroads are scrapping passenger cars today three times as fast as they are buying new ones. According to published reports (2) from 1950 to 1956, railway passenger traffic, in passenger miles, declined from approximately 6.9 percent of the total carried by all forms of transportation to 4.1 percent, bus passenger traffic fell off from about 5.6 percent to 3.6 percent while private automobile traffic increased from 85.2 percent to 88.4 percent and air travel from about 2.1 percent to over 3.6 percent. Surprisingly enough, a small gain is shown for inland waterway passenger traffic, but the total carried is only about 1/4 of one percent.

Similar intercity freight figures for the same period, in ton-miles, show a decline in rail freight in percent of the total volume carried from about 57.4 percent to 49.0 percent, an increase in truck freight from 15.8 percent to 18.4 percent, an increase in inland waterway freight from 14.9 percent to 15.9 percent (this represents an increase in millions of ton-miles from 163,344 to 219,973), and an increase in oil pipeline tonnage from 11.8 percent to 16.6 percent. The air freight remains a negligible amount although increasing slightly.

An important point may be made from these figures which could apply to ship transportation. The equipment and operating methods of the railroads have not changed greatly in the past fifty years, whereas the efficiency and speed of other forms of transportation have substantially improved in the same period. In the latter category it is proper to include inland water transportation, particularly on the rivers. On the Mississippi River system alone (2) the freight traffic has increased in ton-miles from 13,934,427 in 1940 to 56,785,586 in 1956. Over this period the propulsion efficiency of inland waterway transportation has increased substantially. The diesel engine, the Kort nozzle, improved barge design, and integrated barge systems have contributed to the advances in river transportation. This has come about in a large measure through design studies and model research. Water transportation has in this field held its own against other forms of transportation by means of engineering advances which brought about continuing gains in efficiency.

Turning to overseas passenger traffic where the ship and the airplane are the only competitors, another change is taking place. In 1950 (2) ships carried 1,068,648 passengers to and from the U. S., in 1957 this figure was 1,262,687; however, in the same period air traffic tripled increasing from 1,094,628 to 3,052,796 passengers. (These figures include both U. S. and foreign carriers). Aside from passengers carried on cruise ships and ship types fitted for low cost one-class passenger service, it is quite apparent that the bulk of the passenger traffic across the oceans will be carried by airplanes. The era of the large deluxe passenger liners seems to be about over.

In spite of the rather gloomy picture in the ship passenger trade due to the competition from the airplane the ship business is still a growing one. Lloyds' Register of Shipping reported in November 1958 that the world's merchant marine has tripled in the past four decades and has reached a new record size. It was also reported that this fleet totaled 35,202 propelled ships of over 100 tons with a combined total of 118,033,731 gross tons. The increase for the past year was 7,787,650 gross tons, the largest annual increase since 1948. On the other hand the record does not look so good for the United States when the age of the world fleets are considered. Norway and Japan now have fleets which are 69.8 and 66.2 percent, respectively, composed of ships built in the past 10 years, whereas only 7.5 percent of the U. S. fleet is new since 1948. While the U. S. fleet is still the world's largest by a small margin more than half of it is in relatively old tied-up reserve fleet ships. Furthermore, U. S. tonnage has declined by 321,259 tons since 1957. These figures are also borne out by the statistics on U. S. import and export freight tonnage (2) which shows that U. S. flag ships in 1950 carried 43.7 percent of the import tonnage and 32.5 percent of the export tonnage, whereas in 1957 these figures dropped to 20.1 percent and 17.5 percent respectively. This occurred while export and import freight tonnage rose from 159,388 (thousands of short tons) in 1950 to 337,679 (thousands of short tons) in 1957.

The cost of a new ship and the cost of operation of ships is higher than ever before and will go higher. There are some who believe that ship operating costs, particularly the "in port" time and costs, will soon choke off all but essential ship traffic. Subsidies are necessary to meet foreign competition. High operating costs are not restricted to ships, however. The plight of the railroads is common knowledge and many airlines could not operate successfully without subsidies in the form of mail contracts. A recent newspaper article discussed the high cost of the new jet planes and pointed out that the airlines had taken about all of the passengers they could from other forms of transportation. In another article (3) the cost of 44 of the new Boeing 707 and Douglas DC8 jet transports was given as $280,000,000. This is over $6,000,000 apiece--almost the cost of a modern freighter. A new model of the Boeing 707 just coming out will cost even more.

Great changes in the forms of transportation have taken place in the last fifty years brought about by science and engineering, economics, and the irresistible pressure of this civilization for speed. The motor car has replaced the horse and the wagon with a manifold increase in speed. The airplane is rapidly replacing the ship in the overseas passenger carrying field and has taken a large share of the domestic passenger business from the railroads. Tremendous increases in speeds over those of the older forms of transportation have been attained by the airplane. At present economics prevent the airplane from reducing the bulk freight tonnage carried by land transport or by ship, and, although it does not appear likely, the airplane may yet become a serious competitor in this business as well, particularly if nuclear-powered airplanes become a reality. There is good reason to believe that nuclear power will be successfully applied to the airplane within a few years.

The only significant technical advance in the operating efficiency of the railroads has been the replacement of the steam engine by the diesel. This has not caused an important increase in speed although an improvement in efficiency has undoubtedly resulted. What important technological advances have been made in ships in the past 50 years? The steam turbine, high pressure steam, and the diesel engine have caused a substantial reduction in fuel rate and welding has improved hull construction. However, relatively small increases in speed have resulted. The freighters of fifty years ago steamed at 9 to 11 knots while modern freighters, of which the Mariner is an outstanding example, do makes speeds of 18 to 20 knots. Nevertheless, there are many ships operating today at speeds much less than this. Tankers and ore carriers are achieving economic advantages by increases in size without increases in speed. This is a temporary advantage only, however, since the size of the large new tankers and ore carriers has reached a limit due to harbor depths except in the case of tankers where special offshore loading and unloading stations are used. It is not likely that deepening of existing harbors to accomodate these extremely large ships will be practicable; hence they are restricted to a very few trade routes. One alternative method of carrying more tonnage per ship is to increase speed. An increase in ship speed is only a part of the problem. Decrease of "in port" time by improving cargo handling is perhaps the most important area to work on, especially in the case of dry cargo vessels where methods in use today are essentially the same as they were hundreds of years ago.

Many of the cargoes carried by ship are not in the category of premium freight. Thus it is difficult to justify substantial increases in ship speed on economic grounds. In fact, the contrary is often true. For example, the analysis of ship economics presented by H. B. Benford (4) clearly shows that in the case of ocean ore carriers of moderate size speeds of about 15 to 17 knots are best. Unfortunately this state of affairs is strongly influenced by the interrelation of crew costs, government subsidies, and by the insistence of men today to do less work for more pay. This does not mean that if higher speeds are readily obtainable without excessive cost, faster ships should not be built. There may not be economic pressure to increase ship speeds but greater speeds will undoubtedly be used to advantage in some ship types even though cost savings were not the primary motive in the selection of engine powers. Possible future military use does of course demand higher speeds.

Certainly the great speed increases for the airplane since World War II have not been caused by the desire for economic gains. Admittedly much of the technical developments in aircraft have come from research done in military programs but the airlines have not hesitated to utilize these developments to increase the speeds of commercial airplanes.

It is clear from the foregoing figures that the world needs ships and the need is increasing. World trade is obviously growing despite the "cold war" situation which has existed for some time. Also, it is a well known fact that the United States is becoming more and more dependent upon foreign countries for many raw materials. Thus the climate for more and better ships exists in the world today and the position of the United States in this field is in serious need of reinforcing.

Although economics, politics and government have a most important role in determining the state of health of the U. S. merchant marine and U. S. shipbuilding the ship designer must play his part as well. What can the ship designer do to improve the construction costs and operating efficiency of U. S. ships? He has two somewhat conflicting areas in which he can work: one, to reduce the cost of ship construction and operation by careful attention in the design to erection procedures, construction details, hull arrangements, cargo handling, and propulsion efficiency and two, to exploit technological advances to make ships faster, more seaworthy and more maneuverable.

To do the research and engineering studies necessary to produce marked improvements in ships and to reduce their costs requires both time and money. With the present procedures in ship design neither time nor money is available. A new ship is designed much like the last one of its type and the basic plans and specifications can be and are developed in a matter of a few months. In fact, the ship may be built and on trial within one or two years of the start of a design. Large passenger vessels and certain naval vessels of course require a somewhat longer design period. Nevertheless, considering the cost and importance of ships too little time is spent in their design. Why is this so? In part because of the customer's desire to have the ships as soon as possible, in part because of the timing of the financial agreements and because this is the way it has always been done. In the case of naval vessels a great deal of the haste stems from the manner in which congressional appropriations are authorized.

Records of engineering manhours required to do a ship design are difficult to find. Figures published in 1948 (5) show 150,000 manhours for a "Victory" ship and 2,000,000 manhours for battleship. Ships are growing more complicated and the number of design manhours has risen somewhat in 10 years, particularly so for naval vessels. However, figures for one of the newest cargo ships which include the owner's engineering, plan approval, inspection and shipyard design total only 237,000 manhours. A similar figure for one of the latest medium-sized passenger vessels built in the United States is 430,000 manhours. More than one ship was involved in each program.

In the latter two cases cited the manhour figures are considered to be outside figures; the average manhours spent on design and engineering for new vessels in this country today will probably be substantially less. The design and engineering costs for the cargo ships represented about 4 percent of the total cost of the program, for the passenger ships about 8 percent of the total cost.

Records of engineering manhours required to develop a production model of a new airplane are also difficult to obtain. Published figures for the engineering and research manhours expended in the development of the B 52 bomber (6) show that 12,000,000 manhours were used over a nine year period from the date of the specifications to the date of the first aircraft in service. This 9 year period includes 3 years of flight testing of two prototypes. Similar figures for the latest jet transport aircraft are not yet available but it is assumed that the manhours and time were somewhat less than those for military aircraft. However, the development work paid for by the government on military planes undoubtedly greatly aided the engineering involved in the B 707 transport. How much of this can be charged to the B 707 is difficult to assess, but a representative of the Boeing Aircraft Co. indicated the figures for the B 707 would be of the same order of magnitude. Advertisements by the Boeing Aircraft Company indicate that 4 years of test flying preceded service use of the B 707. On the assumption that 10,000,000 manhours were used for the B 707 and based upon published cost figures per plane this represents about 20 to 25 percent of the cost of a 50-plane program.

While these manhour figures for ship and aircraft design are rather sketchy it is quite clear that in general the engineering and research effort put into a new ship is substantially less than for an aircraft and certainly is a smaller part of the total cost of a ship. One of the important differences in the two cases is of course the fact that aircraft are almost always contracted for in relatively large numbers whereas most ships are custom built one or two at a time. Except for some Navy programs only in wartime are large numbers of ships built to one design and even then they are built in a number of different shipyards. It can be argued that ships are much nearer optimum in design than aircraft because of the greater number of years of experience in ship design. It may also be said that the net result of this practice is that less technical progress has been made in ships than in aircraft. The author believes that the latter thesis is pertinent and that more time and effort should be devoted to engineering and research during the development of the design of a new ship.

The ships designed and built in this country in recent years such as the "Mariners", the new supertankers, the "United States", the "Santa Paula" and others are fine vessels and as good if not better than those built in other countries. They can be even better and they must be to continue to compete with other nations on the seas and to provide the U. S. with the fleet that national security demands.

The construction and operation of ships in this country as well as in other countries is closely tied to the policies of the Federal Government. Subsidies of one form or another must continue to provide for shipbuilding and ship operation. But for the U. S. merchant marine to lead the fleets of the world in technical progress all concerned must recognize the need for greater research in naval architecture and marine engineering.

Not many will disagree that more research and engineering should go into the development of a ship design and that it will pay off in greater efficiency. There will, however, be considerable disagreement as to how it is to be financed.

At present the research being done in the ship design field, i.e. research which is specifically directed toward ship problems is largely financed by the U. S. Navy. Although the U. S. Maritime Administration does sponsor engineering development programs and applied research the program of the Society of Naval Architects and Marine Engineers is the only broad research program concerned with merchant ship problems. The funds for this program were contributed by industry and are being used to support many projects covering a wide scope. While the Society's research effort is comparatively small the manner in which it is organized has produced much more than its dollar value through the additional gratuitous contributions of time on the part of many engineers and scientists. It has also initiated projects which were subsequently supported by much more funds from government sources.

Since the U. S. government is so intimately involved in most of the shipbuilding in this country it is logical to look to the government for the financing of a large proportion of the general research which should be done in the problems of ship design. The work carried out at the Navy's David Taylor Model Basin contributes a great deal, particularly in the field of hydrodynamics. As it should be, however, it is largely directed to the solution of problems of importance to the Navy. Expansion of the research programs of the Society of Naval Architects and Marine Engineers would be an excellent way in which to accomplish the necessary work in the merchant ship category. However, the funds available for the Society's program are quite limited at present and it is doubtful whether industry could continuously support a much larger program on a long range basis. It seems appropriate then that the U. S. Maritime Administration be the government agency to support a greater research program in the merchant ship field. If feasible government support of the Society's program through the technical committee now set up would produce the most return for the money invested.

While there is no doubt of the desirability of spending large sums in the research and development of nuclear power for ships the author believes that the expenditure of funds of at least a reasonable proportion of these sums should be devoted to research in ship structure, hydrodynamics, cargo handling and ship operation.

Increasing emphasis on ship research will help in part but the other important area, the engineering studies and design work done during the development of the plans for each new ship is the responsibility of the design activity or shipyard. It is here that more time must be allowed for the many engineering studies needed to thoroughly explore all important details so that substantial advances in ship design can be accomplished.

The suggestion that more time and more manhours be devoted to the development of the ship design implies of course that the design costs will be greater. It is the author's firm opinion that these expenditures will pay for themselves in reduction of ship construction costs, decreased maintenance costs, increased propulsion efficiency, and improved operating efficiency. Even though engineering costs are doubled, these costs would still represent a small part of the total cost of a ship or group of ships.

It is obviously not feasible to build prototypes of new ships as is the practice during the development of a new airplane before finalizing a design although it is possible that this might be done in the case of multiple ship programs of some small naval vessels. In a few instances this procedure has been followed in the procurement of small craft for the Navy. So much can be done through engineering studies and through model experiments that it is not necessary to expend large sums in full scale work.

There are many areas in naval architecture and marine engineering where additional research effort is needed. One of the most important of these is in the field of ship operations and is perhaps not in a strict sense the naval architect's responsibility. Certainly when the building of a new ship is contemplated the prospective operators will want economic justification for it and furthermore will make some sort of a study to determine the optimum size and speed for the ship. Many of the factors involved in such studies will be influenced by the domestic and the international political situations. However, much can be learned through the methods of operational analysis applied to ship operation and from economic studies similar to those by Benford (4) and (7). Promising savings in operating time and fuel costs are being shown through the use of optimum weather routing of ships (8). Some ship operators and naval architects have made analyses of the types mentioned but it is believed that further exploitation of modern methods will be worthwhile.

It is likely that most naval architects and ship operators will agree that it is in the area of cargo handling where most is to be gained, particularly in the case of dry cargo vessels. Much work has been done in this field and improvements have been made. The National Science Foundation and the International Cargo Handling Coordination Association are carrying out work in this important field. A number of specialized ships have been built to improve cargo handling time, "roll on roll off" ships and container cargo ships among them. If ship research and engineering studies can be increased, the category of cargo handling should receive a great deal of attention. The present trend seems to be in the direction of special purpose ships, and it is probable that this is the most profitable course. Recent construction of a wine carrying ship may lead to development of special types for carrying other bulk foods and liquids. The author believes that greater use of working models to study ship arrangements, movement of cargo, etc., would help the designer.

A ship's structure is an extremely complex one and subject to many types of loading, the magnitudes of which are to a great extent known only within rather wide limits. Much has been learned about the design of satisfactory hull structures since the advent of steel ships and what qualities of steels or other materials are needed. Unfortunately, a portion of the knowledge has been obtained through the experiences with costly ship failures. While some of these difficulties with ship structure have arisen because of the lack of an understanding of sea loadings too many of the troubles arose from poor design practice or through inadequate information on the behavior of materials.

The rules of the classification societies furnish an excellent guide to the design of hull structure; however, they are largely of empirical origin and are not flexible enough to permit ready development of optimum structure for all types of ships. Furthermore, the use of the rules for all merchant ship design tends to lead too much to standardized design based upon conservative approaches and discourages the development of more rigorous design methods.

Although the design of the hulls of naval vessels is carried out in a more fundamental manner and as a result produces structures of less weight than those which would obtain through the use of merchant ship standards, there is still a large region of uncertainty. In a paper presented at the last annual meeting of the SNAME Evans (9) points out some of the areas in which further investigation is needed.

The problems in ship structural design are quite similar to those in aircraft design except that weight is of prime importance in aircraft structure and only of secondary importance in most ship hulls. As a result, the aircraft designer does a much more detailed stress analysis and resorts to extensive structural tests of plane components and complete full-scale assemblies. A similar procedure is followed in the design of submarine hulls by the Navy. While strength data on full scale hulls are obtained in test dives after the submarine has been completed, the use of structural models of submarine hulls during the design stage has proved to be an invaluable tool to the naval architect.

The paper by Vasta (10) is an excellent discussion of the important findings from the full scale tests of ships' structure, and the paper by Ochi (11) describes the use of a structural model for experiments in ship slamming.

The work of the Ship Structures Committee, the Society's structure committees, the American Bureau of Shipping, and the Navy in this field have increased the knowledge of the behavior of materials, methods of design, etc., but these are not enough. Greater effort should be directed toward the development of more nearly optimum hull structures. Important research is being done in the area of sea loadings and the effects on ship bending moments. Among others the work of Lewis at the Experimental Towing Tank at Stevens Institute of Technology and Jasper at the David Taylor Model Basin is contributing substantially to the effects of ship motions and **waves** on hull structure.

While it is highly desirable to refine the design of a ship's structure so that a minimum of steel is used, it is also vital to keep construction costs to a minimum. These two objectives to some extent oppose each other. The most suitable compromise must be sought. Greater standardization of design details, the elimination of sheer in the parallel middle body, simplified ship form, the use of rolled steel shapes for welding without cutting are some of the possibilities where construction cost savings may be made. The author believes that research and engineering in the whole scope of structural design and construction should be expanded.

More research is being done in ship hydrodynamics than perhaps any other area. The greater part of it is being carried out by the David Taylor Model Basin. An excellent summary of the research sponsored by the Navy is given in the Journal of Ship Research (12), (13). While much of the Navy's work is of particular interest to the Navy a great deal of it is applicable to ships in general. The programs of the Hydrodynamics Committee of the Society cover many of the problems in hydrodynamics of importance in the merchant ship field. Nevertheless, greater efforts are needed to solve the problems still existing and to provide information for the naval architect who is attempting to design a new ship which will have better seakeeping characteristics, have an optimum hull form and propeller for propeller for efficient propulsion, and be free of vibration. Additional guidance in these important design matters is needed.

The use of nuclear energy to propel ships is just beginning. At present the cost of a nuclear plant and its fuel is so large that it is not likely to be immediately used for merchant ship propulsion except for special ships such as the "Savannah". The rapid advances in science and technology today, however, make it quite possible that nuclear power for ships will be economically advantageous in the near future. When this comes about it is almost certain that ship speeds will increase. How much depends in part on what the ship designer can do to develop a hull which will be seaworthy, have adequate strength and can be propelled at high speeds efficiently and without vibration.

Most of what is known about ship form, propellers, propeller-hull interaction, and hydrodynamic-excited hull vibration has been learned from model or full-scale experiments. In past years there have been sporadic attempts to explore these areas theoretically. Some of the efforts have furnished useful tools for the designer or guided further experimental research. In recent years additional progress has been made in hydrodynamic theory. Propeller design for example is successfully accomplished through theoretical treatment although certain empirical data must still be used with the theory. If real progress is to be made in the hydrodynamics of ships, the research in these directions must be intensified. St. Denis and Craven have described some of the latest developments in hydrodynamics of ships in the Journal of Ship Research (13).

There has been a substantial increase in research in the area of ship motions and seaworthiness. There have been a number of papers on ship motions published in the Society of Naval Architects and Marine Engineers transactions in the past few years. Korvin-Kroukovski at Stevens Institute of Technology has been engaged in the preparation of a monograph on seakeeping which will summarize the work done to date and outline the paths for future work. This project is being sponsored jointly by the Ship Structure Committee and the Society of Naval Architects and Marine Engineers. Publication of Kroukovski's work is expected in the near future.

One of the most important and vital steps which has taken place in the past few years is the collaboration of the oceanographers and the ship hydrodynamicists to seek a technique for mathematically describing the surface of the seas. This joint work should be encouraged and exploited further.

It would be a serious omission if one other problem having to do with ship construction and operation were not mentioned. The multitudiness and overlapping government agencies engaged in regulating, approving and financing shipbuilding and operation create cost increases which need not occur. This subject is a complicated one and cannot be discussed here. Suffice to say a comprehensive and intelligent overhaul of these government functions and the regulations involved could do much to help ship designers, builders and operators and undoubtedly save the taxpayer substantial amounts.

Greater knowledge must be obtained where there are gaps in the technology of ship design by stimulating interest and supporting research to a much greater extent than heretofore. The schools where naval architecture is taught must encourage the students who have strong abilities in the scientific areas to do graduate work in some of the problem fields, and industry and government must find ways to support these efforts.

Naval architects have been slow to exploit information already available from research work previously accomplished in the laboratories. This is caused in part by the lack of time in the design stage in which to interpret technical reports and develop useful design data. Furthermore, some of it is due to the fact that the researcher often does not recognize the need for the engineer to have the results of research put into the engineer's language.

There are a number of areas in which ship improvements can be brought about with present knowledge. These include the development of more specialized ship types to reduce cargo handling time and in port costs such as "roll on roll off" ships, container ships and other ships designed for carrying specific commodities and simplification of hull structure through greater use of standard details, employment of more straight lines in hull form, development of rolled steel shapes more suitable for welding with a reduction in cutting.

There are important possibilities for general improvement of propulsion efficiency, seaworthiness, and vibration which have not been fully exploited. In recent years the Navy has shown through full-scale trials that rough paint surfaces and general hull finish can increase hull resistance by very large amounts (14). Careful attention to paint and other roughnesses such as welding beads and structural details can save appreciable power.

Some research has been done recently on the effectiveness of fixed anti-pitching fins installed low at the bow (15) and (16). It has been shown by model experiment that such fins reduce motions and improve dryness of decks. The Navy is experimenting with these fins on a full-scale vessel.

The use of contra-rotating propellers to propel ships, that is two propellers on the same shaft centerline rotating in opposite directions, is not new. Torpedoes have employed this propeller system for years and John Ericsson tried them on a ship as early as 1837. Recently contra-rotating propeller design methods have been developed by Lerbs (17) and van Manen (18). Efficiency gains of from 5 to 10 percent may be realized over conventional single-screw ship propulsion. Furthermore, the possibility of reduced propeller excited vibration is likely. While the design of inner and outer shafts and the bearing arrangements may be somewhat complicated it is believed that the problem can be readily solved. It is possible that a contra-rotating steam turbine may be developed for use with these propellers. Reduced propeller diameters over that required for an optimum single screw will enable higher powers to be accomodated with better hull efficiencies than those for twin screws.

Recently two German ships were built with unusual provisions for reducing propeller blade-excited vibration (19). The essential feature common to the two ships is a very large propeller clearance obtained by mounting the propeller on an extended shaft bossing so that the distance of the propeller from the stern frame is well over a propeller diameter and the tip clearance appears to be more than one half a propeller diameter. These are single-screw ships with spade rudders. The larger of the two ships which is approximately 400 feet in length with a speed of 17.8 knots has a torpedo shaped bossing worked into the skeg. Reports indicate a gain in propulsive efficiency due to the more uniform wake and a remarkably vibration-free ship. This ship also has a somewhat simplified stern shape which should reduce construction costs. The important feature, however, is the bossing shape and propeller clearance. These features are in the author's opinion worth investigating further for application to future U. S. ship designs.

The short period of time allowed for development of a new ship design may cost the owners as much as 3 to 5 percent in propulsive efficiency for the life of the ship. In spite of the large amount of data available on resistance of hull forms and propeller characteristics it is probably safe to say that on an average the ship designer's initial attempt at hull lines and propeller design is somewhat less than optimum. And in too many cases model tests are carried out on one set of lines and on one propeller design only. In the authors experience it is generally possible to improve hull and propeller efficiency by at least 3 to 5 percent if the model program is extended sufficiently to permit tests of two or three hull designs or modifications of the basic design and tests of two or three propellers. Such a model program would cost from about

$10,000 to $25,000 today for a single-screw ship depending on the towing tank used. Yearly fuel costs vary considerably with type of ship and service. On the basis of today's fuel prices published data indicates that the total fuel bill for a year may be as much as $100,000 to $400,000 for a dry cargo ship, $500,000 to $700,000 for a larger tanker or ore carrier and as much as $1,000,000 or more for a large passenger ship. It needs no further explanation to see that the cost of model tests would be paid off very soon if only a small increase in propulsive efficiency is obtained. Certainly this is worth serious consideration when planning the model program for a new ship. Furthermore, a little more attention to hull structural details, periodic hull painting and cleaning of the propeller might save another 2 to 3 percent. It is quite possible total savings in horsepower might average as much as 5 to 10 percent.

There are other benefits to be derived from model tests although somewhat less tangible. Model seaworthiness tests, flow tests, and steering and maneuvering tests can lead to better performing ships. The model studies to explore propeller-excited vibration causes and cures sponsored by the Society of Naval Architects and Marine Engineers will result, it is hoped, in test techniques which can be applied to new ship designs. All of these different types of model tests should be performed on each new important ship design and in the author's opinion will pay for themselves in superior ship operation. It is difficult to establish limits of expenditures for model tests for a new ship design but the author believes that model programs costing from about $35,000 for a moderate size cargo vessel to as much as $100,000 for a large fast passenger ship can easily be justified. Unfortunately the time element enters into this matter, and to carry out such programs the model basins in this country must be able to do much better than they now do, on an average, to complete the work within design schedules. Model test programs should be anticipated as much as possible to enable shcedules to be met and additional time allowed in the design period.

There are many areas where ship design can be improved, where important gains in efficiency can be obtained, and where ship construction costs can be reduced. To thoroughly investigate these possibilities and exploit the knowledge already gained and to be gained from research requires more engineering manhours per ship design. The time spent in the design and engineering of a ship is a small part of that used in the development of a new jet aircraft. Great gains in aircraft design have been realized in a very few years. The author believes that the cost and importance of a ship justifies greater engineering efforts and a substantial increase in ship research. Only by designing ships through the use of greater scientific and engineering approaches can improvements in ships keep pace with the rapid technological advances being made every day in other fields.

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